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Infrared thermal imaging of the inner canthus of the eye as an estimator of body core temperature

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Several studies suggest that the temperature of the inner canthus of the eye (T_{ca}), determined with infrared thermal imaging, is an appropriate method for core temperature estimation in mass screening of fever. However, these studies used the error prone tympanic temperature as a reference. Therefore, we compared T_{ca} to oesophageal temperature (T_{es}) as gold standard in 10 subjects during four conditions: rest, exercise, recovery and passive heating. T_{ca} and T_{es} differed significantly during all conditions (mean $\Delta T_{es} - T_{ca}$ 1.80 ± 0.89°C) and their relationship was inconsistent between conditions. Also within the rest condition alone, intersubject variability was too large for a reliable estimation of core temperature. This poses doubts on the use of T_{ca} as a technique for core temperature estimation, although generalization of these results to fever detection should be verified experimentally using febrile patients.

Keywords: Thermography; Thermometry; Body temperature; Exercise; Fever

1. Introduction

The outbreaks of pandemic infections such as SARS in 2002/2003 have called for a method that allows mass screening for fever detection. Infrared thermal imaging is mentioned as an appropriate technique for mass screening of fever [1]. The temperature of the inner canthus of the eye (T_{ca}) seems the most suited spot [2] although others argue that the average temperature of the face may be valuable as well, albeit in combination with other physiological parameters [3]. A recent review observed a wide range in fever detection sensitivity from 4 to 90%, while specificity ranged from 75 to almost 100% [4]. All studies in the review used (infrared) tympanic measurements as a reference. However, it is well documented that these measurements may deviate considerably from the core temperature as assessed using more reliable methods such as oesophageal temperature [5]. Therefore, this study aimed at determining the value of infrared measurements of the inner canthus of the eye (T_{ca}) compared to oesophageal measurements (T_{es}). In order to obtain reproducible conditions, exercise and heat exposure were used to modify the body core temperature instead of fever.

2. Methods

2.1. Subjects

Ten healthy and fit subjects (six males and four females) with a mean age of 25.8 ± 3.9 years and a mean weight of

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72.3 ± 4.6 kg participated in this study. Subjects were requested to follow their usual diets and lessen physical activities the last day before each trial. Each subject was fully informed of the purposes, protocol, experimental procedures and any associated risks and benefits before giving their written consent to participate. The experiment was approved by the Ethics Committee at TNO.

2.2. Protocol

The test procedure consisted of three sessions on separate days with at least one day in between: one preparatory session, one experimental session in which the subject was actively heated by exercise and one experimental session in which the subject was passively heated by a water perfused suit. The experimental sessions were offered in balanced order.

In the preparatory session subjects completed an informed consent and anamnesis form. Subjects not familiar with the oesophageal probe tested their tolerance by inserting this probe. In case of severe gagging reflexes they were excluded from the study.

At the active heating session, subjects first redressed into sport clothes and inserted a rectal and oesophageal probe. A heart rate sensor and skin temperature sensors were attached. After about five minutes, when the oesophageal probe had stabilized, the measurement started with 20 minutes rest in the climatic chamber (30°C). This was followed by a 10-minute submaximal exercise test that started at an intensity of 130 W. This was, if necessary, increased till subjects reached a heart rate of about 150 beats per minute. Then subjects had two minutes rest, before they performed a maximal exercise trial of eight minutes. They were instructed to cover as much distance as possible during these eight minutes. Thereafter, they had 10 minutes of recovery (pedalling quietly at low intensity) before the experimental session stopped.

The passive heating session started with a rest measurement of 10 minutes in the climatic chamber (30°C). Then the subject put on the water perfused suit which was set at a temperature of 45°C. The subjects sat down for 40 minutes while their core temperature was increased passively. The complete experimental protocol is summarized in table 1.

2.3. Materials

Experiments were carried out in a custom-made climatic room (Weiss Enet, Tiel, The Netherlands). Temperature was set at 30°C with 50% relative humidity. The 30-min exercise protocol was performed on a Lode Excalibur bicycle ergometer (Lode, Groningen, The Netherlands). To get an indication of the intensity at which the subject was performing, heart rate was measured using a Polar Vantage NV sport tester (Polar Electro, Finland) at a 5-second interval.

T_{ca} of the eye was measured using a FLIR ThermaCAM SC2000 PAL infrared camera (Flir, Breda, The Netherlands). The camera was positioned at about 1.5 m from the face. IR measurements were made at different time intervals during the active and/or passive heating sessions (table 2).

T_{es} was measured using a thermistor (Yellow Springs Instruments 700 series, Yellow Springs, OH, USA). This thermistor was calibrated before data acquisition in a thermal water bath (Tamson TLC-15, Tamson instruments, Bleiswijk, The Netherlands) using a certified Pt100 calibration thermometer (P650, Dostmann Electronic, Wertheim-Reicholzheim, Germany) with resistance temperature sensor (PD-13/S, Tempcontrol, Voorburg, The Netherlands). The subjects inserted the oesophageal sensor themselves through the nasal passage. The insertion depth beyond the nostrils was determined according to the formula of Mekjavic and Rempel [6] based on sitting height. The T_{es} sensor was attached to a

Table 1. Experimental protocol of the active heating session and the passive heating session. Sessions were offered in balanced order.

	Time (min)	Activity	Intensity
Active heating session	0–20	Rest	
	20–30	Submaximal exercise	HR ± 150 bpm
	30–32	Break	
	32–40	Maximal exercise	8 min self-paced
	40–50	Recovery	
Passive heating session	0–10	Rest	
	10–20	Putting on tubed garment suit	
	20–60	Passive heating (sitting)	T set at 45°C

Table 2. Overview of infrared images made during the rest, exercise and recovery phase of the active heating sessions and during the passive heating sessions.

Subject	Rest	Exercise	Recovery	Passive heating
1				X
2	X	X		
3	X		X	
4	X		X	X
5	X	X		
6		X		
7	X		X	X
8	X		X	
9			X	X
10		X	X	

custom-made data acquisition system (VU, Amsterdam, The Netherlands), consisting of a data logger with medical power supply and Labview software (National Instruments, Austin TX, USA). Sample frequency was 1 Hz.

Mean skin temperature (T_{sk}) of the body was determined by averaging the results of four i-buttons (DS1922L, Maxim Integrated Products Inc, Sunnyvale, CA, USA) as described by ISO 9886 [7]. See [8] for an evaluation regarding the use of i-buttons. A sample frequency of 0.1 Hz was used.

2.4. Data analysis

Maximal T_{ca} on each image was determined with ThermaCAM Explorer software (Flir, Breda, The Netherlands). T_{es} data were gated to remove the negative peaks due to swallowing. Then T_{ca} measurements were matched with the T_{es} and T_{sk} measurements at the exact moment of the IR image. Averages per phase of the experimental sessions were calculated for T_{es}, T_{ca} and T_{sk}, as well as differences and standard deviations (SD) for each T_{es}/T_{ca} data pair.

A Bland-Altman diagram [9] was constructed for all data pairs to visualize the deviation between T_{es} and T_{ca}. In this diagram, the average value of two compared temperatures is depicted against their difference. It also indicates the 95% limits of agreement (LoA) for these measurements at two standard deviations of the difference.

3. Results

Table 3 gives the measured values of T_{es}, T_{ca} and T_{sk} averaged over the different phases of the experimental sessions.

The differences between T_{es} and T_{ca} at different trial conditions are shown in figure 1. The differences were significant for all periods ($p < 0.05$).

The Bland-Altman plot (figure 2) for all collected data points shows a mean difference of 1.80°C and a standard deviation of 0.89°C, resulting in 95% limits of agreement of 0.03 to 3.57°C.

Table 3. Values (±SD) of oesophageal temperature (T_{es}), infrared canthus temperature (T_{ca}) and skin temperature (T_{sk}) averaged per phase of the different experimental sessions.

Phase	N	T_{es}	T_{ca}	T_{sk}
Rest	6	36.87 ± 0.29	35.60 ± 1.04	32.61 ± 1.01
Exercise	4	38.35 ± 0.90	35.53 ± 0.43	33.67 ± 1.12
Recovery	6	37.87 ± 0.33	35.87 ± 0.74	34.14 ± 0.82
Passive	4	37.03 ± 0.30	35.75 ± 0.44	36.61 ± 0.42

In figure 3, the same data points are depicted as a function of T_{es} only. The solid line is the linear fit which describes the relationship between T_{es} and the difference between T_{es} and T_{ca} ($\Delta T_{es} - T_{ca}$). The dotted line shows the best fitting regression line with a fixed slope of 1.0. This line reflects the situation in which the change in T_{es} would be fully responsible for the change in $\Delta T_{es} - T_{ca}$.

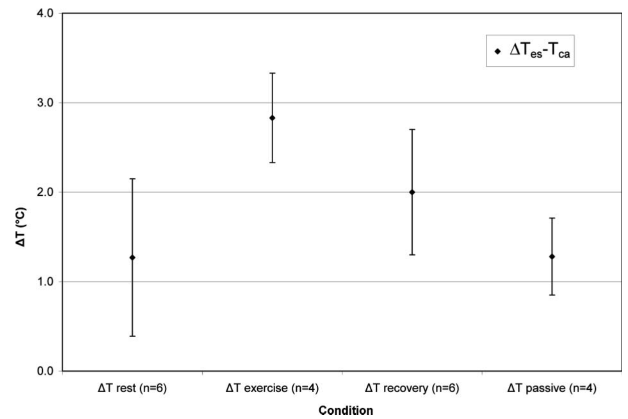

Figure 1. Difference (± SD) between infrared temperature of the inner canthus of the eye (T_{ca}) and oesophageal temperature (T_{es}) during rest, exercise and recovery of the active heating session and during the passive heating session in 30°C ambient temperature.

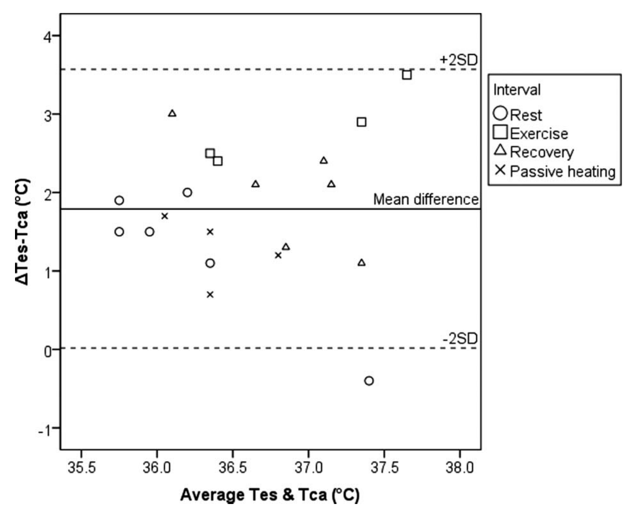

Figure 2. Bland-Altman diagram for oesophageal (T_{es}) and infrared temperature of the inner canthus of the eye (T_{ca}), showing the difference between T_{es} and T_{ca} ($\Delta T_{es} - \Delta T_{ca}$) as a function of the average of both temperatures. Symbols indicate during which intervals a measurement was made: circles for rest, squares for exercise, triangles for recovery and crosses for passive heating.

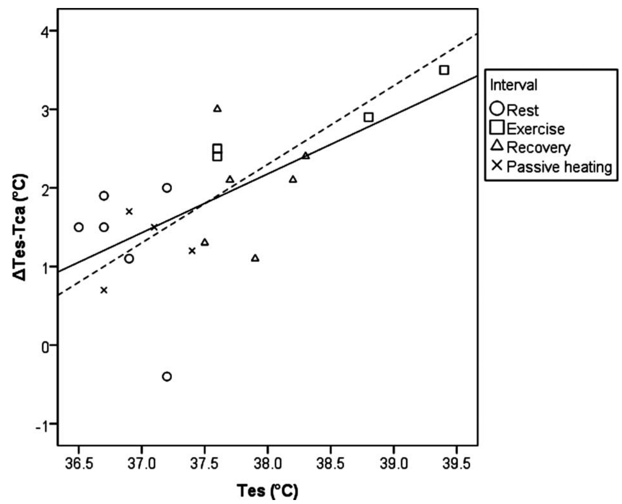

Figure 3. Scatterplot for the difference between oesophageal and infrared temperature of the inner canthus of the eye ($\Delta T_{es} - \Delta T_{ca}$) as a function of oesophageal temperature (T_{es}). Symbols indicate during which intervals a measurement was made: circles for rest, squares for exercise, triangles for recovery and crosses for passive heating. The solid line shows the linear trend for all datapoints, the dotted line is the best fitting line of identity (slope = 1.0) which would indicate that the increase in $\Delta T_{es} - T_{ca}$ is entirely due to the increase in T_{es}.

4. Discussion

The study shows that the radiant temperature of the inner canthus of the eye (T_{ca}) has a poor and inconsistent relation with oesophageal temperature (T_{es}) during rest, exercise and recovery.

In rest, T_{ca} was about 1.3°C lower than T_{es} (figure 1). During exercise, the average difference between T_{ca} and T_{es} increased to 2.8°C. The increase in core temperature during exercise, as reflected by the rise in T_{es}, was largely invisible in T_{ca}. So $\Delta T_{es} - \Delta T_{ca}$ increased almost proportionally to T_{es} (figure 3), while a consistent relationship between T_{es} and T_{ca} would have been reflected by a horizontal line. Therefore, it can be concluded that T_{ca} is not suited for estimating body core temperatures during exercise. Looking at the measurements in rest separately, adding a constant to T_{ca} does not yield a reliable estimator of body core temperature either, because of the large inter-subject variation. The passive heating trials indicated that this variation was decreased when subjects wore a water perfused suit, which possibly created a more homogeneous temperature distribution among subjects. However, the standard deviation of 0.46°C does still not allow for reliable core temperature estimation. Unfortunately the passive heating protocol was not forceful enough to result in hyperthermic core temperatures, so a comparison with fever is not feasible.

Although exercise and fever both result in increased body core temperatures, one could argue that the measurements made during and after exercise are not representative for fever because of differing thermoregulatory mechanisms. In fever, the core temperature set-point is increased due to pyrogens that enter the blood stream and trigger the hypothalamic neurons [10]. Therefore, thermoregulatory responses are directed at the attainment and maintenance of an elevated core temperature. In human exercise, it is generally believed that the increased body temperature results from a delayed onset of heat loss mechanisms and that the set-point does not increase. After exercise, heat loss exceeds heat production and this induces a core temperature drop back towards the fixed set-point [10, 11]. The following considerations regarding this discrepancy between fever and exercise hyperthermia are relevant for the current experiment.

T_{ca} depends on the skin temperature (T_{sk}) of the inner canthus. If exercise and fever have a comparable effect on T_{sk} of the inner canthus, our results on exercise hyperthermia could presumably be generalized to fever hyperthermia. However, to our knowledge, inner canthus T_{sk} has not yet been determined during exercise and fever in the same subject. Mean T_{sk} data suggest that T_{sk} during fever may be higher than during exercise [12]. Lenhardt *et al.* [12] induced fever (38–38.5°C) in 11 subjects during a control condition (supine position, only covered by a cotton blanket) and a self-adjust condition (subjects could control their warming themselves). In these conditions, skin temperatures started at a level comparable to the current study (32.5–33.0°C), but reached about 1 (control) to 2.5°C (self-adjust) higher peak values than during exercise/recovery of the current study. Considering these data, generalization from exercise to fever seems unwarranted.

Nevertheless, if T_{ca} really is a reliable, broadly applicable measurement method, it should reflect oesophageal temperature for every thermal state of the body, regardless of the way this status is achieved (rest, exercise, passive heating or fever). This is not the case and therefore it poses serious doubts on T_{ca} as an estimator of body core temperature.

Further, as Cabanac [13] pointed out, there may not be a fixed set-point in human thermoregulation. He argues that the set-point is continuously adjusted, for instance for body fluid control. This makes fever and exercise hyperthermia more comparable in thermoregulatory aspects. In both cases an increase in body core temperature and skin temperature is observed. In addition, Kenny *et al.* [14] showed that whole body heat loss is rapidly reduced after exercise, despite the fact that body heat content, muscle temperatures and oesophageal temperatures are still elevated (47% of the heat stored during exercise was not dissipated after one hour recovery, while heat loss mechanisms were back at baseline). Therefore, it is possible that a set-point increase occurred during and after exercise, albeit of minor amplitude.

In conclusion, T_{ca} is not a good estimator of core temperature during exercise and recovery hyperthermia. Possibly, this conclusion extends to fever as well, but experimental verification using febrile patients is necessary.

Finally, two recommendations for future research may be made.

In many studies concerning fever screening with infrared imagery, (infrared) tympanic temperature has been used as a reference to establish the validity of the method. However, the use of (infrared) tympanic temperature as a reference during fever is not acceptable, since tympanic temperature is error prone and dependent on variables as ambient temperature and ear canal morphology [5]. For properly establishing validity, it is therefore recommended that future studies use a reliable method, such as oesophageal or intravenous temperature measurements.

Unfortunately, it was not feasible to measure T_{ca} for each subject for each thermal condition. However, in mass screening, many different people in different physical states pass the system. Therefore, a consistent bias for different physical states with a small inter-subject variation is a prerequisite. This study suggests that infrared imagery may not fulfil this prerequisite. Future studies should provide more insight into this issue, varying external and internal conditions for larger groups of subjects and structurally using reliable core temperature references.

Declaration of interest: The authors report no declarations of interest.

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